CHAPTER XV

AUTOMATIC RANGING CIRCUITS

1. Applications of Automatic Ranging Circuits

As described in Chapter X, a cathode ray tube is normally employed in radar sets for display purposes, but there are occasions when it is desirable to make the radar information available in the form of a meter indication or the angular displacement of a shaft. This occurs in certain airborne gun-directing sets which use automatic circuits to feed range directly to the gun computer, thus eliminating the radar operator. Again, in the field of navigational aids for civil aircraft meter indicators for the pilot are preferable to cathode ray indicators for a number of reasons. Among these are the economy of dash-board space achieved by the meter, the elimination of difficulties produced by large variations in ambient light intensity, and smooth presentation of information to the pilot who cannot afford to look at a cathode ray tube for signals which may be fading or obscured by interference.

Meter indicators may be used with either self-synchronised or externally synchronised radars. The first type covers distance-measuring radars in which a measurement is made of the time interval between the emission of pulses from a local transmitter and the reception of echoes from targets or of beacon responses. The second includes the hyperbolic navigational systems in which the measurement of the time delay between pulse transmissions received from fixed ground stations locates an aircraft or ship on a known line. Examples of the two applications are outlined in Chapter XX.

In both of these cases meter-indicating circuits operate in virtually the same fashion, so that the following description will be based on a self-synchronised system with a short note on the adaptation to an externally synchronised system.

Operation in the presence of complex echo patterns, such as are obtained from ground reflections, is of course beyond the capabilities of an automatic circuit and the application is therefore limited to those radars in which only discrete targets or beacon responses are picked up.

2. General Principles

Under ideal conditions the measurement of time delay between two trains of pulses, as shown in Fig. 304 (*a*), might be achieved very simply by feeding them as trigger pulses to a suitable multivibrator circuit, thereby producing a rectangular voltage wave [Fig. 304 (*b*)] of duration equal to the time delay. The

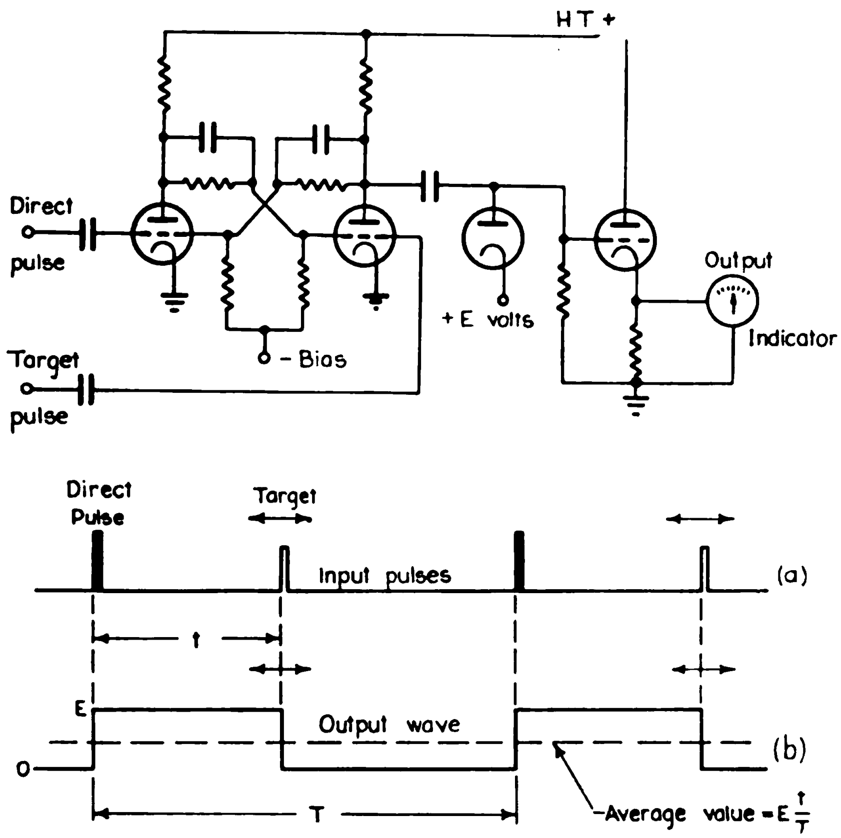

Figure 304.—Simple method of measuring range when only one target pulse and no interference is present.

average value of such a rectangular wave is proportional to its duration so that its application to a suitably calibrated moving-coil meter would give a direct indication of distance. However under practical conditions the picture of received pulses is more likely to be as shown in Fig. 305 where there is more than one target or beacon from which pulses arrive somewhat intermittently, and accompanied by varying degrees of inter-

ference. In this case the simple directly-actuated circuit described above will fail completely, and it is clear that a practical circuit must have properties which allow it to pick out the right pulses, and to give a smooth output reading with intermittent input information. The development of such a circuit follows logically from a study of the more familiar and flexible cathode ray tube display. The latter has some form of recurrent time base on which is displayed the video

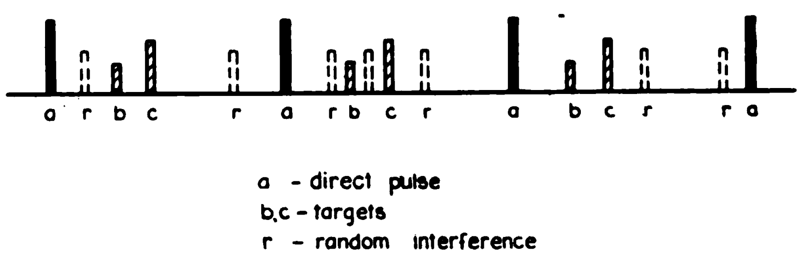

Figure 305.—Typical pattern of received pulses under practical conditions.

output from the receiver during a certain time interval after the transmitter pulse. In using this display the eye searches along the time base for a synchronised signal, and completely disregards all random pulses. On finding the required signal the search is stopped and its distance is measured off the appropriate scale. Should the signal fade for short intervals its position is remembered and it is picked up again when it reappears. The velocity of the target may also have to be remembered if its movement during fades is appreciable.

An auto ranging unit will therefore possess the following electronic counterparts of the above visual processes (Fig. 306):

(*a*) A short gate pulse, generated after each transmitter pulse and movable over the time delay interval appropriate to the radar (the " eye " mechanism).

(*b*) A gated or coincidence amplifier to which this gate pulse is fed together with the video output of the receiver, and which only delivers an output when the gate pulse coincides in time with a video pulse. This is the mechanism of " seeing " a pulse. Actually it turns out that two gate pulses

are needed, one just behind the other and feeding two gated amplifiers, to gain information as to the direction of movement of the target.

(*c*) A variable delay circuit for setting the position of the gates, controllable by means of a DC voltage, which is also applied to a meter calibrated in terms of range.

(*d*) A slow sweep voltage generator to be connected to the delay circuit so that the gates can be swept in and out in search of a target.

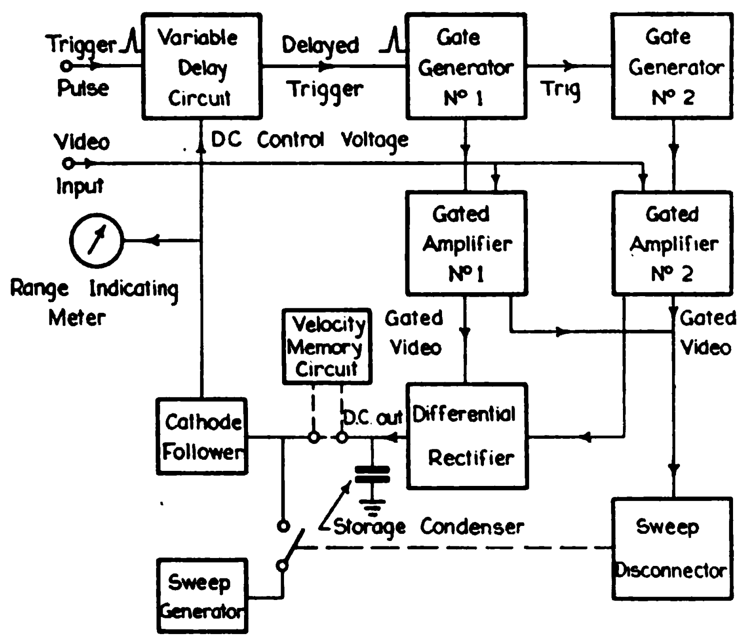

Figure 306.—Block schematic diagram showing the component parts of an automatic ranging unit.

(*e*) A sweep disconnector to stop the search when a target is found. This will include some form of pulse counter to discriminate against random pulses, and there will also be a suitable delay before the search is switched on again after a target disappears.

(*f*) A tracking mechanism consisting of a differential rectifier fed from the two gated amplifiers, and providing an increasing or decreasing DC output according as the target overlaps one gate more than the other. This, when applied to the delay circuit, will keep the gates moving along with the target.

The rectifier must have a large storage condenser which will maintain a substantially constant potential during signal fades, thus giving position memory. A cathode follower will be necessary to provide DC isolation between the condenser and the metering circuits.

An alternative tracking method which may be adopted in special circumstances is to provide the DC control voltage from a motor driven potentiometer, the motor speed and direction being controlled by a differential field system fed from the rectified gated amplifier outputs.

(*g*) If more than one target is present a trip button will be required to release the circuit from one target and allow it to look for the next one.

(*h*) An additional velocity memory circuit may have to be introduced if the motion of the target during periods of fading is liable to take it out of the gates.

There are many features of a " servo " mechanism in the above items, and the general theory of servos[1] is applicable to some aspects of the circuit design.

3. Circuit Design for a Self-Synchronised Radar

Variable Delay Circuits

The delay circuit is the heart of an auto ranging system and is discussed first. Any of the types described in Chapter XIV may be used although the phantastron is usually chosen because it combines good stability with reasonable economy in the number of tubes required. Two typical circuits for a 100 mile maximum delay phantastron are given in Fig. 307 using a 6SA7 pentagrid tube and a CV138 (miniature pentode) respectively. Minimum delay is commonly about 1 per cent of the maximum. Where the control voltage is directly metered, as in these circuits, the anode load of the phantastron may be made much smaller than the conventional value because a little current flowing through the anode diode will have no effect on the metering circuits. The cathode follower between

[1] G. S. Brown, " The behaviour and design of servomechanisms," National Defense Research Committee, Section D-2 Report, November, 1940; and H. Harris, Jr., " Analysis and design of servomechanisms," National Defense Research Committee, Section D-2 Report, undated.

anode and grid may then be eliminated. Miniature tubes in general seem to be much less stable in delay circuits than their full sized counterparts, probably because of their more delicate construction. A 6SN7 twin triode used as a delay multivibrator will give reasonable stability, but a 6J6 miniature tube in a similar circuit may suffer from drifts of 2 to 3 per cent of the maximum delay.

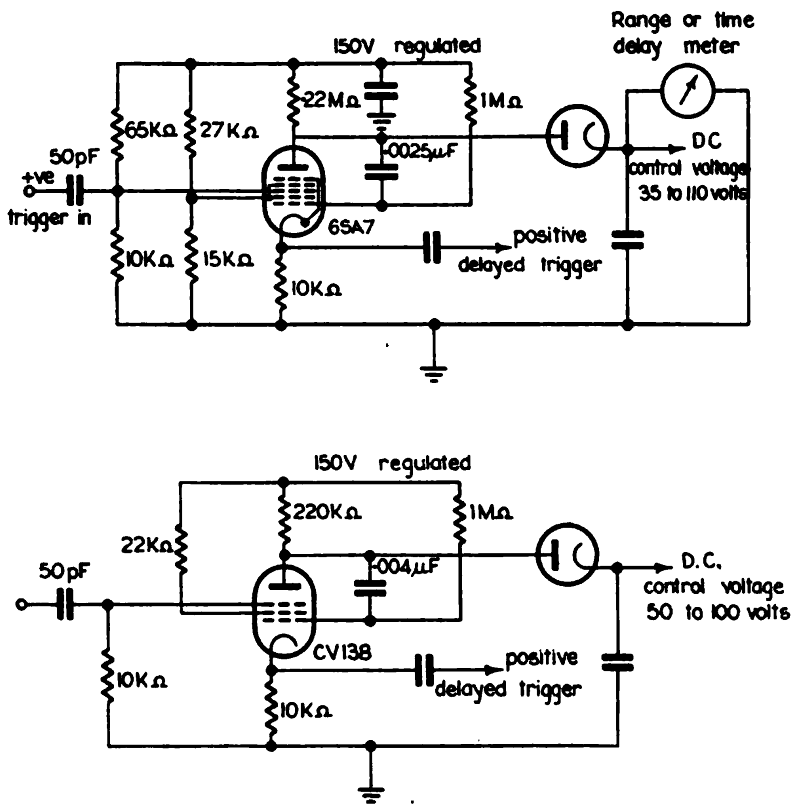

Figure 307.—Typical phantastron variable delay circuits.

Gate Generators

Any of the methods of generating short pulses described in previous chapters may be used to produce the delayed gates. In general the blocking oscillator method is the most useful as it gives a pulse at low impedance with a small high tension drain. A typical circuit for generating a pair of 4 microsecond gates in rapid succession is given in Fig. 308. Here the tail of the first pulse triggers the second oscillator. It is

also sometimes possible to use the positive overswing on the anode winding of a single blocking oscillator as the second gate pulse. The required length of the gate pulses is a compromise between two factors. Firstly a high speed of search is naturally desired and this dictates a wide gate so that targets can

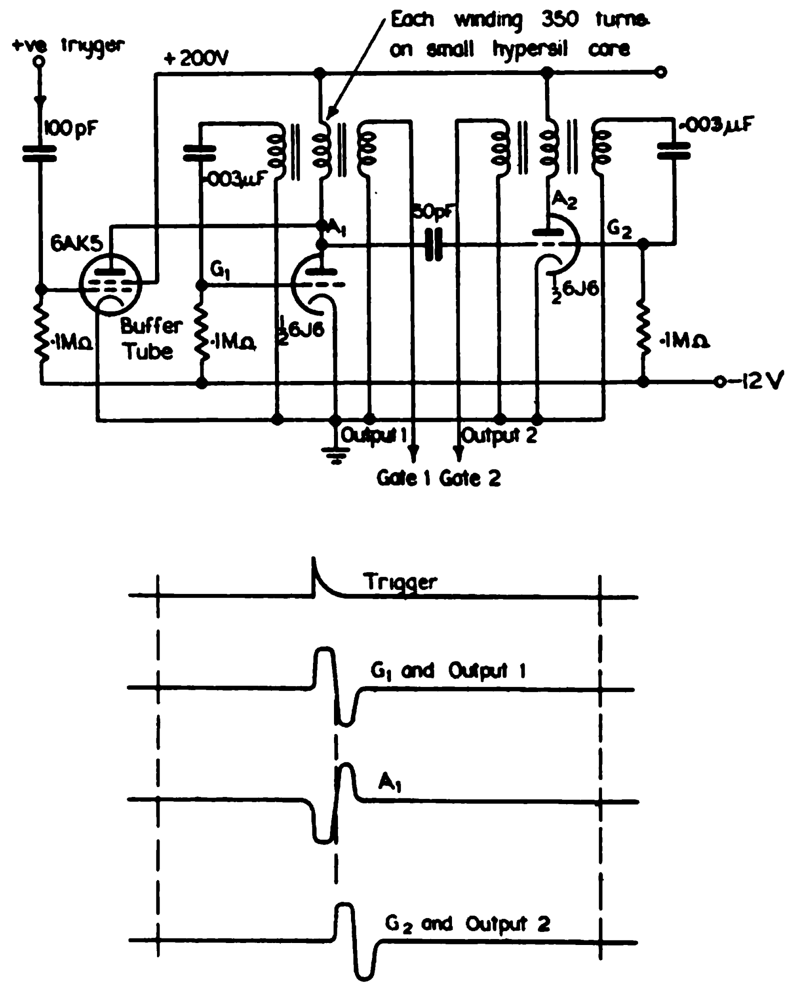

Figure 308.—Circuit for generating short gate pulses using a blocking oscillator.

be " seen " before the gate runs through them. Secondly a narrow gate is required to prevent interference getting through sufficiently often to actuate the search disconnector. The probability of this occurrence may be calculated for any given set-up, and should be made suitably low by choosing the correct gate length.

Gated Amplifiers

Any multiple grid tube will serve as a gated amplifier. Positive video signals are fed to one grid and positive gate pulses to

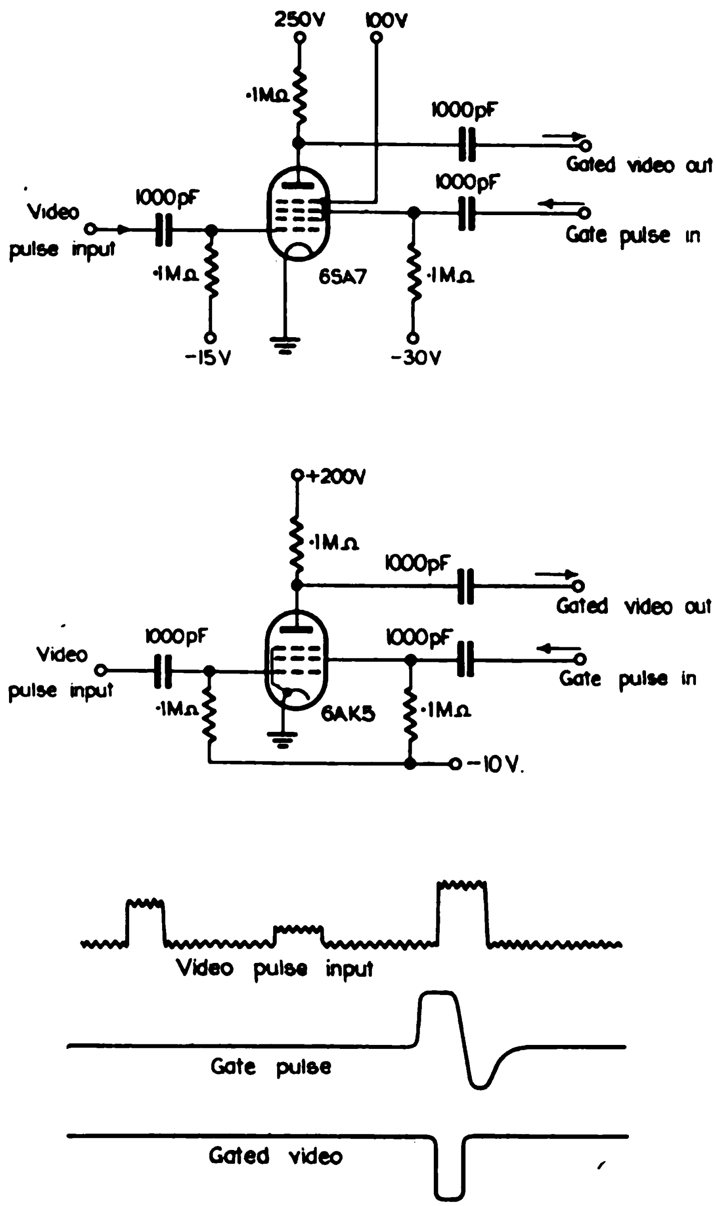

Figure 309.—Gated amplifier circuits using 6SA7 and 6AK5 tubes.

another grid, both having a cut-off bias applied. The result is that anode current can flow only when both grids are " on " simultaneously and the output at the anode consists of negative

pulses whose duration corresponds with the overlap between gate and video pulses. These are hereafter called "gated video pulses." Fig. 309 gives typical circuits and waveforms. Where a screen grid is used for gating in tubes in which the suppressor is internally connected the gate pulse generator must be capable of supplying the screen current required by the tube.

Differential Rectifier

The differential rectifier is required to produce a rising or falling DC output according as one or other of the gated amplifiers is producing longer gated video pulses. This potential being fed back to the delay circuit will then tend to hold the gates centrally over the target. Fig. 310 (*a*) shows

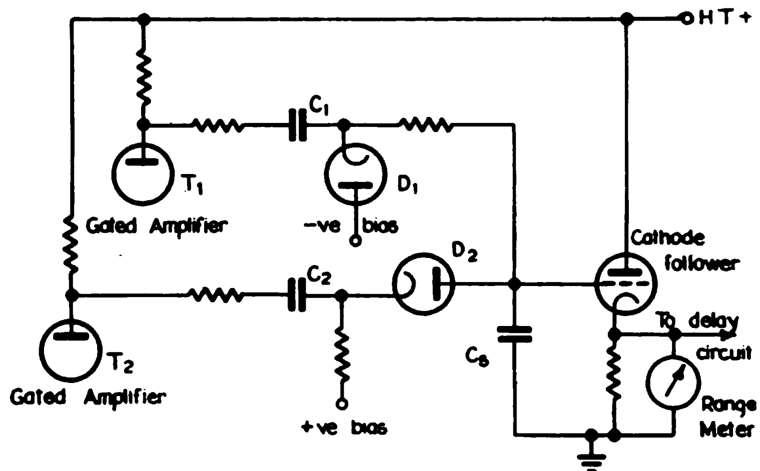

Figure 310 (*a*).—Differential rectifier circuit using a pair of diodes to produce a DC voltage suitable for maintaining the variable delay circuit in track with the target.

a circuit using two diodes feeding in opposite directions to a common storage condenser. Diode D_1 conducts for the duration of each gated video pulse from T_1, and the condenser C_1 acquires a proportional charge which subsequently is fed into the storage condenser C_s. Similarly D_2 conducts for the duration of each gated video pulse from T_2, taking a proportional charge out of C_s. The net effect is that the potential on C_s remains constant if the two gated amplifiers

produce equal pulses, increases if the upper one produces longer pulses, or decreases if the lower one does so. In the absence of signals both diodes are non-conducting so that the

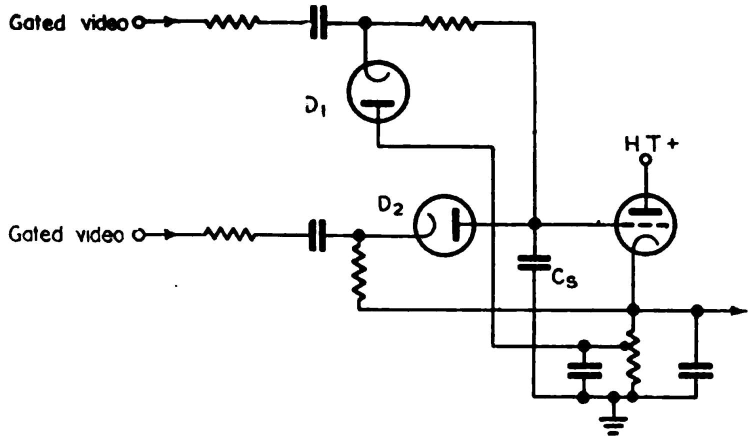

Figure 310 (*b*).—Circuit of Fig. 310 (*a*) modified to produce an approximately constant DC bias on the diodes.

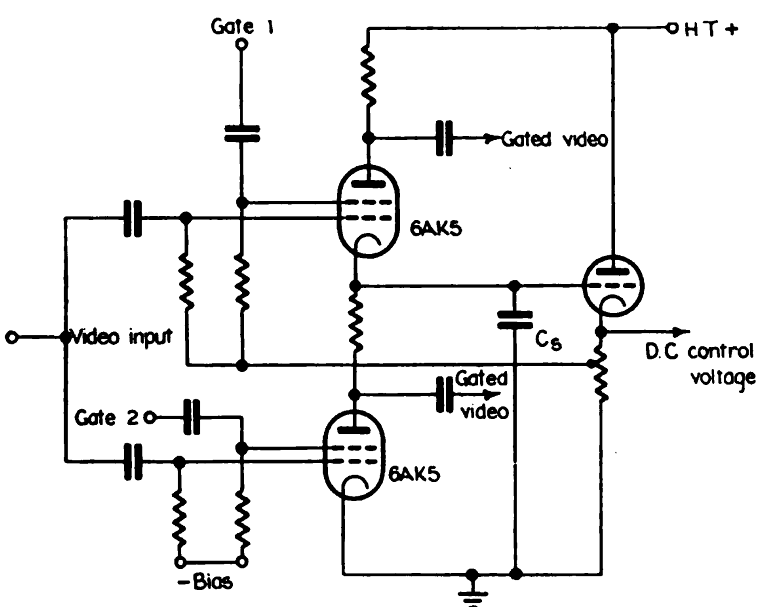

Figure 310 (*c*).—Differential rectifier using two pentodes.

condenser C_s maintains its potential constant to the extent determined by leakage, which must be kept small. In this circuit the bias on the diodes varies according to the potential on C_s so that there are varying delay voltages to be overcome

before the diodes conduct. This effect can be minimised by connecting the diodes to the cathode follower load as in Fig. 310 (*b*).

When a relatively small range of potential is required from C_s it is possible to eliminate the diodes and use the arrangement of Fig. 310 (*c*). Here the gated amplifiers are connected one above the other, one feeding charge into and the other taking charge out of the storage condenser. With this connection, however, the gated video pulses vary in amplitude.

Search Sweep Generator

Searching may be accomplished by connecting the storage condenser C_s into a suitable relaxation oscillator circuit. Fig. 311 (*a*) illustrates a typical circuit in which the storage condenser is charged at a slow rate through a high resistance connected to the high tension supply and a thyratron is arranged to discharge the condenser when the gates have been swept out to the maximum time delay. The grid of the thyratron is returned to a point on the cathode load of the cathode follower to make its point of firing more definite than would be obtained with a fixed bias.

An interesting sweep circuit using a pentode tube is shown in Fig. 311 (*b*). This is termed a "scansitron"[2] and combines both a transitron and a feedback time constant action. In operation the grid potential tends to rise by charging through the grid leak R, but with an amplified time constant ARC, where A is the stage amplification. The potential at the grid therefore rises linearly and the corresponding fall in anode potential is also linear. This fall continues until at low anode potentials the screen current increases and causes the screen potential to fall. The screen is coupled to the suppressor so that the potential of the latter also falls causing a reduction in anode current with a corresponding increase in screen

[2] I. N. Vaughan-Jones, "Notes on transitron circuits," Ferranti Report INVJ5, May, 1944.

current. At a certain point this action becomes regenerative, the suppressor is cut off altogether and the anode returns to the high tension level. The suppressor then recovers according to its time constant and when anode current can flow again

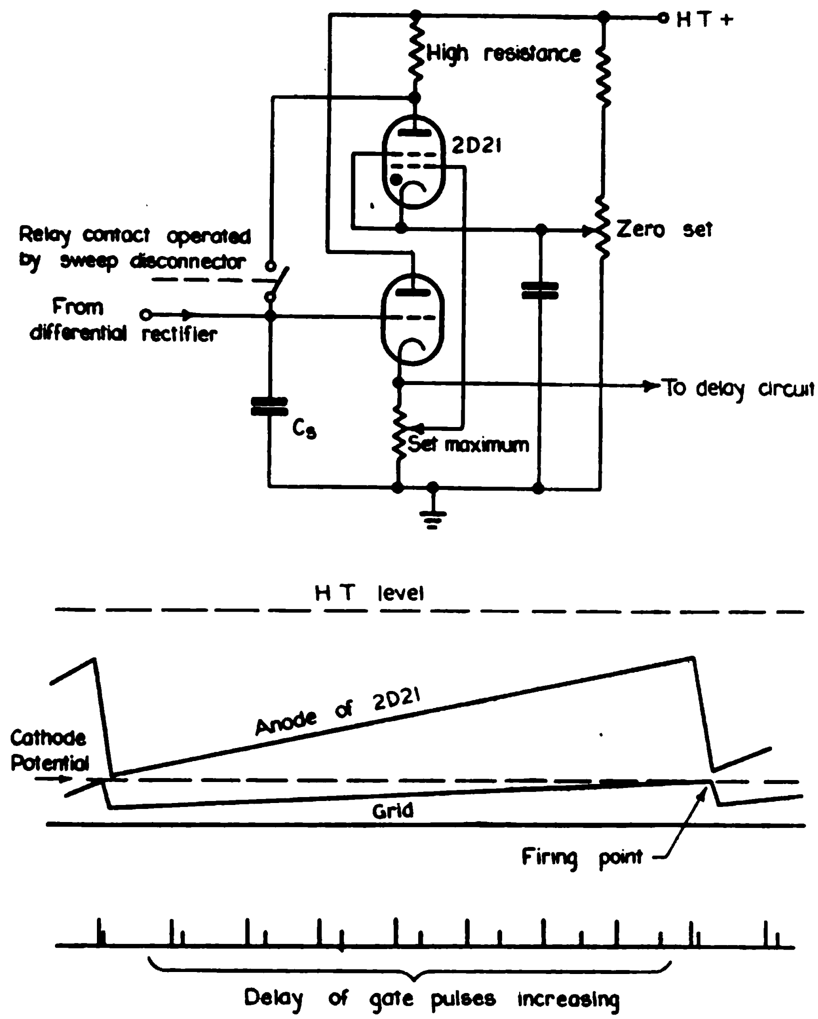

Figure 311 (a).—Circuit for producing a slow sawtooth sweep voltage. This is applied to the variable delay circuit to cause it to search for a target.

the anode and grid potentials drop rapidly together by an amount approximately equal to the grid base of the valve. The screen is then restored to normal potential and the cycle repeats from this point. Values shown on this circuit will

give a sweep time of about 10 seconds with a short recovery time. The grid leak may be open circuited at any point on the sweep and the anode potential will remain constant except

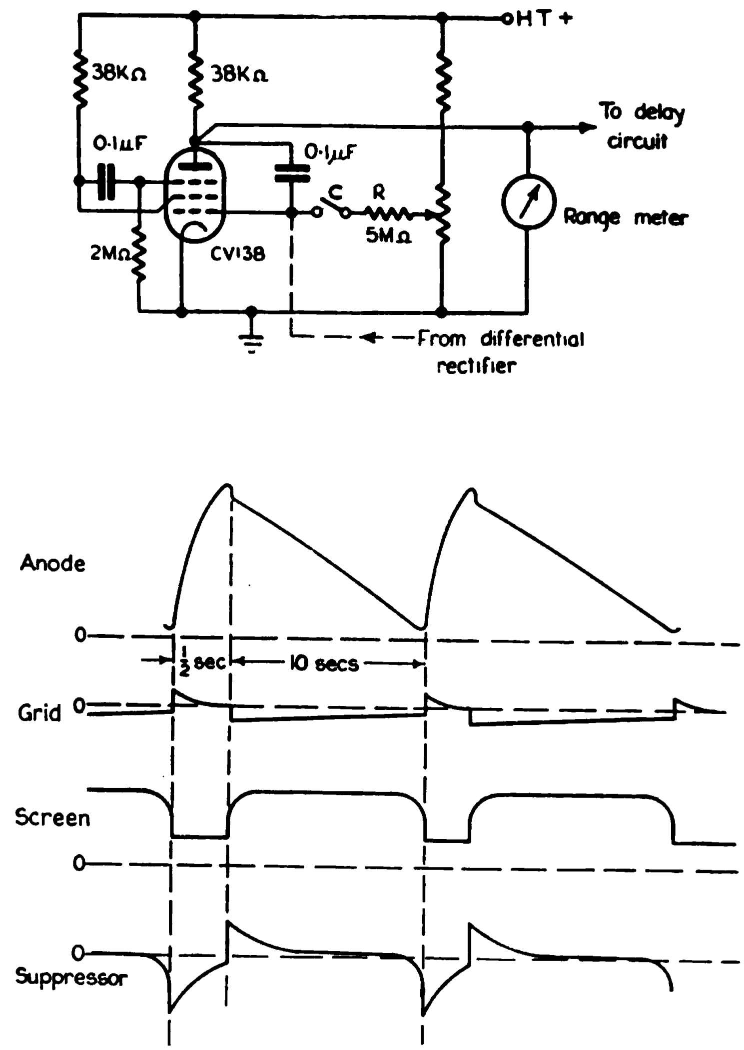

Figure 311 (*b*).—Alternative sweep generator using a pentode in a "scansitron" circuit.

for small leakage effects. The condenser *C* then acts as a large storage condenser and the differential rectifier can be fed directly into the grid. Thus sweeping and tracking are accomplished with a single valve. There is however a slight

disadvantage in that the sweep goes negative and therefore the search proceeds from maximum to minimum range.

A further refinement which may be incorporated in the design of the sweep circuit is to proportion the components so that the average rectified current produced by each gated amplifier is approximately equal to the current flowing into the storage condenser via the charging resistor. In this case whenever the gate which provides tracking in the direction opposite to the sweep encounters a pulse the sweep is halted. The average sweep rate may then be considerably increased because the gates will stop at a target and allow the sweep disconnector ample time to operate.

Sweep Disconnector

A sweep disconnector circuit is illustrated in Fig. 312 suitable for a radar working with a pulse repetition frequency of 100 cycles per second on beacons with a 4 microsecond pulse. Pulses from both of the gated amplifiers are fed to the diode T_1 whose charging time constant R_1C_1 is such that a gated video pulse builds up a positive potential of about four volts at the grid of T_2 for this particular example. The discharge time constant R_2C_1 is such that about two volts of this leaks away in a repetition period. As the gates are moved out in range they make chance encounters with random pulses which produce momentary positive pulses at the grid of T_2, but the effect of these pulses is not cumulative since they are fairly widely separated. However when the gates encounter the beacon pulse a rapid succession of gated video pulses is produced and the potential at the grid of T_2 builds up faster than it leaks away. The cathode of T_2 follows this rise and causes T_3 to conduct, closing the relay in its anode circuit and disconnecting the sweep. If the signal fades the potential at the grid of T_2 drops but the cathode cannot follow it down because of the long time constant R_3C_2, and the relay remains

closed. If the signal disappears altogether the relay opens after several seconds.

When " on-off " coding of the beacon is used the code may be reproduced by a neon lamp in the anode circuit of a valve T_4 whose grid is connected to the grid of T_2.

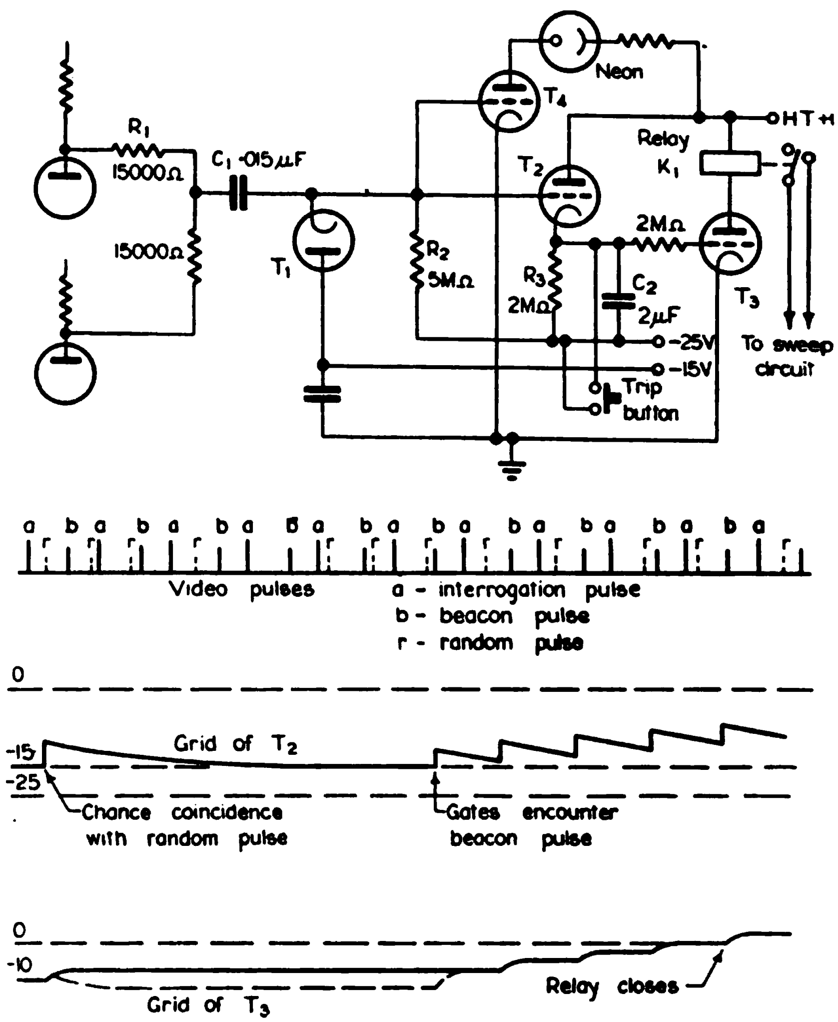

Figure 312.—Circuit for disconnecting the search sweep from the variable delay circuit when a target is found.

Trip Button

By momentarily shorting the cathode condenser of T_2 the relay K_1 can be made to open and allow the search to carry on to pick up targets at greater distances.

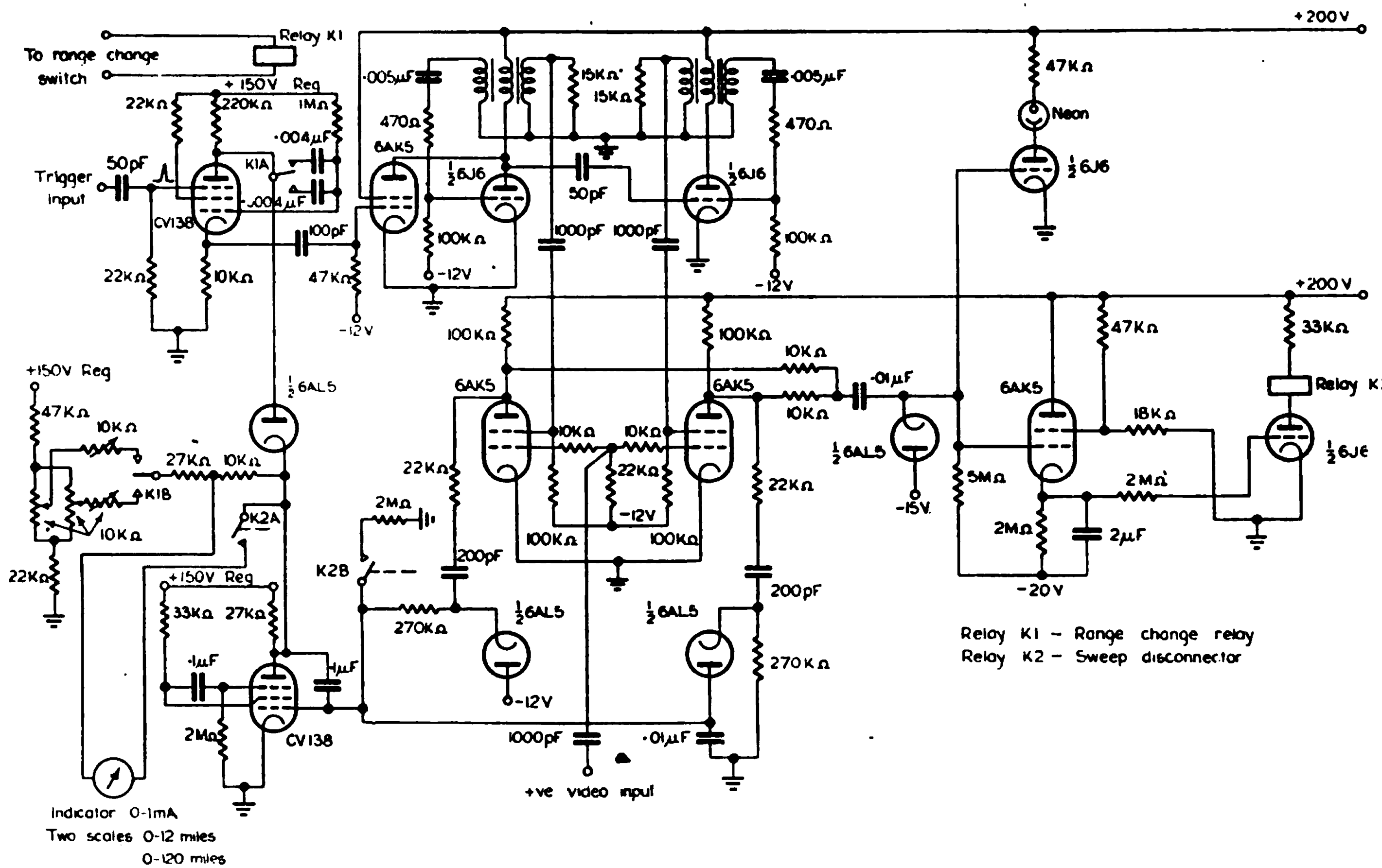

Figure 313.—Complete circuit of an auto-ranging unit built up of the foregoing component parts.

Complete Circuit

Fig. 313 shows the complete circuit of an experimental automatic ranging unit designed for a 100 mile interrogator-responsor set, and using miniature valves. A picture of the unit and its indicator is given in Plate XXI.

Velocity Memory and Measurement of Rate

In the circuits of Fig. 310 an additional resistance-capacity combination may be interposed between C_s and the delay circuit as shown in Fig. 314. Under equilibrium conditions,

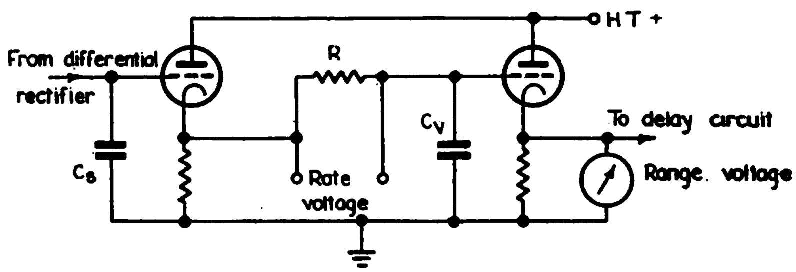

Figure 314.—Velocity memory circuit for maintaining the tracking motion of the variable delay circuit during periods of fading.

with a target moving at constant velocity, the circuit will then settle down with a current i flowing into the condenser C_v of such a sign and magnitude that the rate of change of voltage $dV_c/dt = i/C_v$ keeps the gates moving along at the same speed as the target. The storage condenser C_s will assume a potential which when applied through the associated cathode follower will produce the above mentioned current in the resistance R. Since dV_c/dt is proportional to the rate of change of range, the potential drop across R, i.e. $Ri = RC_v dV_c/dt$, is a measure of the velocity of the target. If the signal fades the gate velocity is maintained substantially constant for times short compared with the time constant RC_v. This time constant, which may be called the " velocity memory time constant," is made as large as possible. An analysis of the transient operation of the circuit shows that " hunting " may easily occur and circuit constants must be chosen for any particular set-up so that this effect is eliminated or minimised.

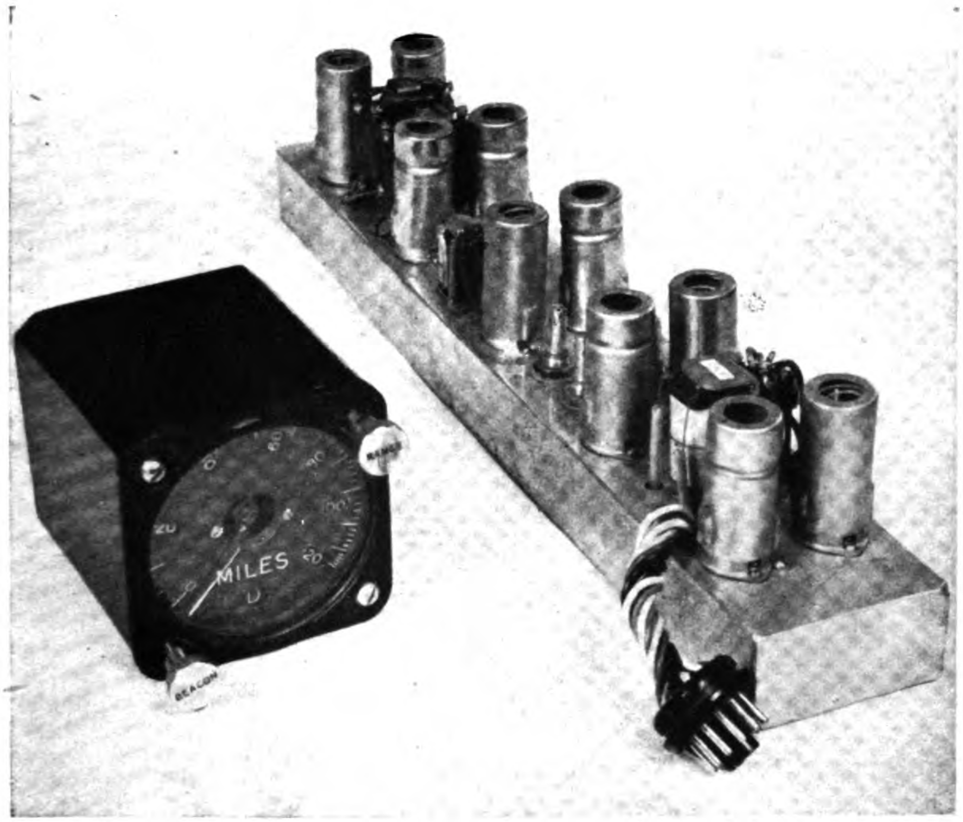

Plate XXI.—An auto-ranging unit and indicator, using miniature tubes.

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Rate or velocity may also be measured in circuits without velocity memory by differentiating with respect to time the delay circuit control voltage using a circuit of the type shown in Fig. 315.

With the control voltage changing at the rate dV_c/dt according to the movement of the target a voltage is produced across the resistance R_1 of magnitude $R_1C_1\ dV_c/dt$. This gives a

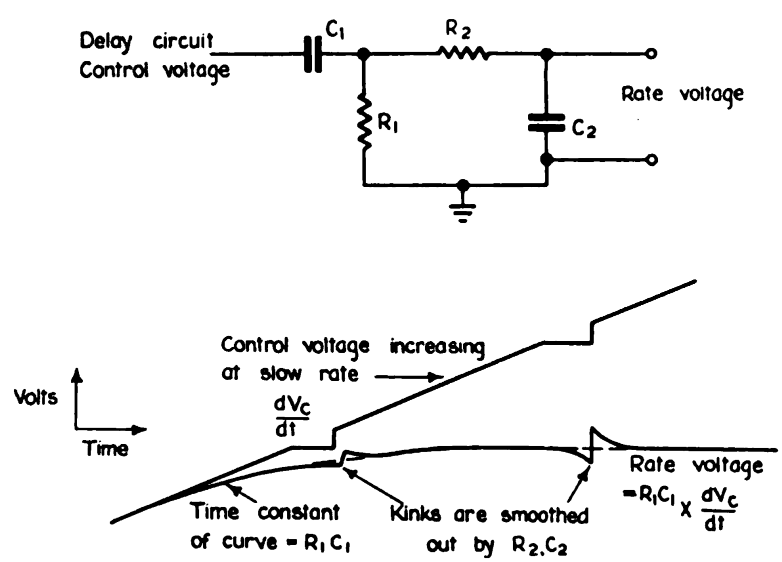

Figure 315.—Circuit providing a direct indication of target velocity.

measure of the velocity, but the voltage settles down with a time constant R_1C_1. The value of this time constant must be chosen as a compromise between adequate output voltage and sluggishness of operation. Since the slope of the curve of control voltage versus time will normally have discontinuities when signals fade, a suitable series time constant R_2C_2 is inserted to filter out these discontinuities.

Sensitivity to Weak Signals

By careful adjustments an automatic ranging circuit can be made to lock on and track with a signal to noise power ratio somewhat less than unity, but for reliable operation the signal to noise ratio should be greater than 2 : 1.

4. Circuit Design for an Externally Synchronised Radar

In an externally synchronised system such as the multiple track system of Chapter XX, section 2, the time delay is measured between two trains of pulses usually known as the "master" and "slave" transmissions, both of which appear at a common receiver output. It is desired to trigger the delay circuit by means of the master pulses and lock the gates on

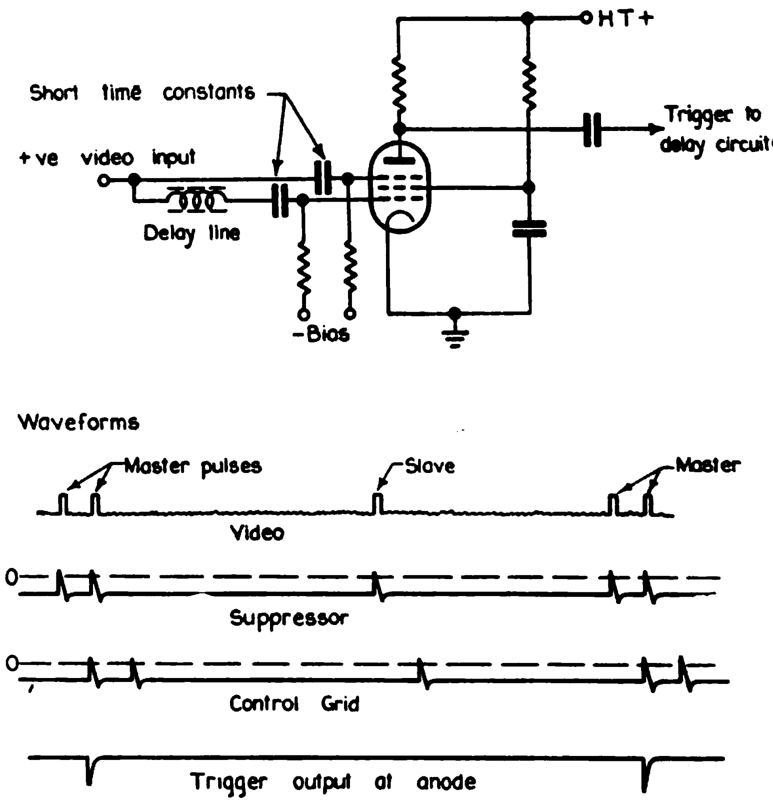

Figure 316 (*a*).—Discriminator responsive to double pulse transmission from master station.

to the slave pulses, at the same time ensuring that interference pulses do not cause an undue rate of triggering. Selection of the master pulses may be effected by giving them a special characteristic or an exact repetition frequency, and by using a discriminating circuit on the receiver output which is sensitive to this pulse characteristic or repetition frequency within a narrow tolerance.

An arrangement of the first type is illustrated in Fig. 316 (*a*) in which the master station transmission consists of double pulses. Positive pulses are fed direct to the suppressor of a pentode tube and also to the control grid through a network which introduces a delay equal to the pulse spacing. Both grids have cut-off bias applied, so that a pulse is produced in the plate circuit only when the second of the two pulses arrives at the suppressor simultaneously with the delayed arrival of the first pulse at the control grid. Applying the pulses to the grids through a short time constant differentiator ensures that only the leading edges of the pulses are effective at the grids. This makes the discrimination sharper and prevents a single long pulse from actuating the circuit. The pulse output from the anode may then be used to trigger the delay circuit.

The alternative circuit using a selector sensitive to repetition frequency is shown in Fig. 316 (*b*). In this circuit T_3 and T_4 form a multivibrator using stable components so that its natural frequency will hold to within a few cycles per second over long periods. This is set at a slightly lower frequency than that of the ground station to which it is desired to synchronise, by means of a DC bias control on T_4. Positive video pulses are fed to the grid of T_1 whose anode is connected to the anode of T_3 and whose suppressor is capacity coupled to the anode of T_4. Assume for the moment that the multivibrator has been synchronised by a " master " pulse, so that the anode of T_3 has swung negative and that of T_4 positive (see waveforms). The anode of T_1 is now below its cathode potential while the suppressor is held at cathode potential by the diode T_2. Under these conditions pulses on the grid of T_1 have no effect in the anode circuit. When the multivibrator completes a half-cycle determined by the time constant R_2C_2 and the DC bias oontrol, potentials reverse and the anodes of T_1 and T_3 are now positive, while the anode of T_4 and suppressor of T_1 swing negative. Pulses on the grid of T_1 still have no effect in the anode circuit because the suppressor is now cut off. However the suppressor recovers according to the time constant R_1C_1, which is adjusted so that the cut off level is crossed (point " a ") just before the next master

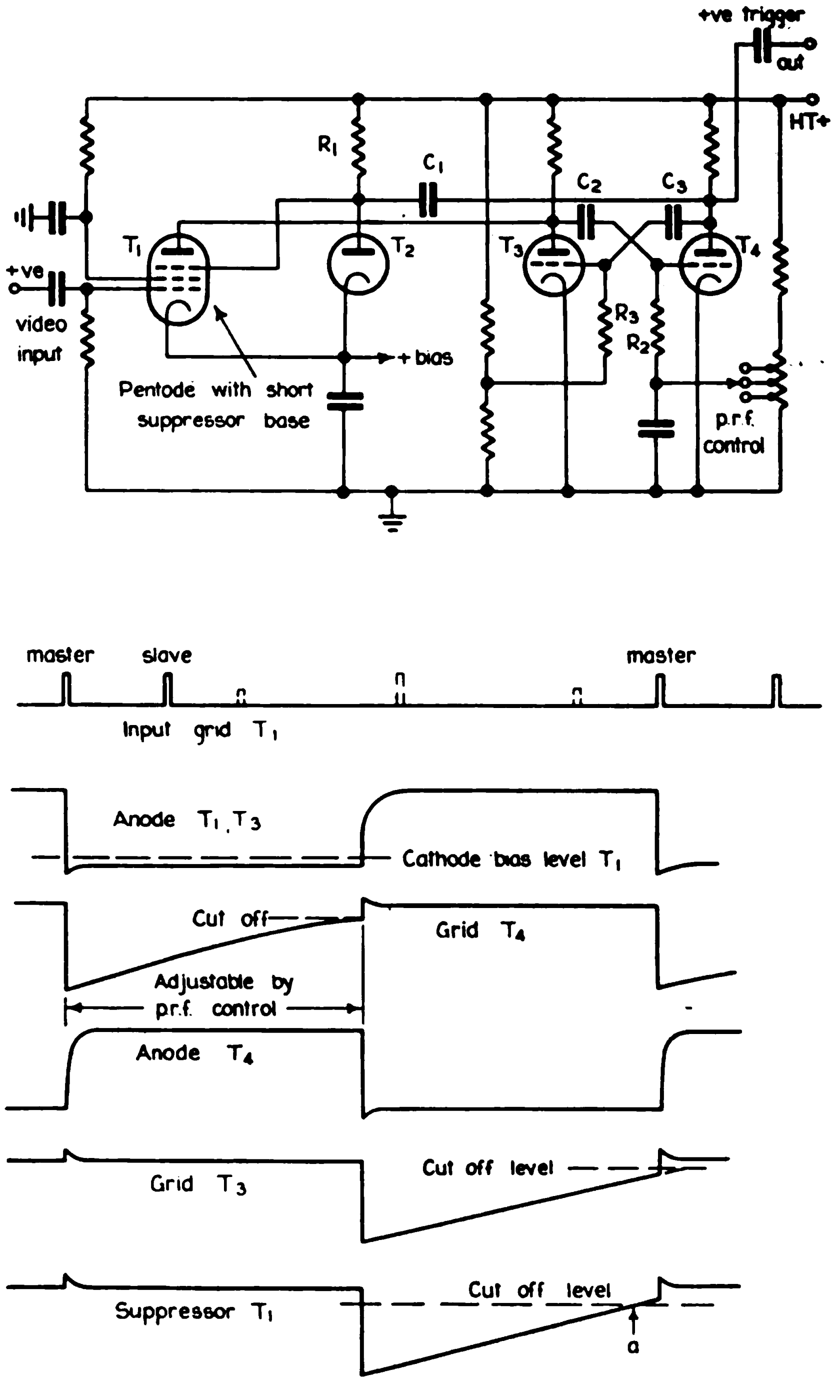

Figure 316 (*b*).—Selector responsive to pulse repetition frequency of master station.

pulse arrives. The multivibrator itself is at this stage very near changeover and any pulse on the grid of T_1 produces a negative pulse at the anode of T_3, tripping the multivibrator. With careful adjustment of the time constant R_1C_1 the circuit can be made quite selective so that, for example, pulse repetition frequencies more than 10 cycles per second in 2,000 off the correct frequency will not synchronise the multivibrator, although an adjustment for $\pm$ 20 cycles selectivity in 2,000, i.e. 1 per cent, is regarded as a good working figure. With the arrangement described above it is of course possible for the circuit to lock on to the " slave " pulses. This can be avoided by a scheme such as missing out alternate slave pulses.

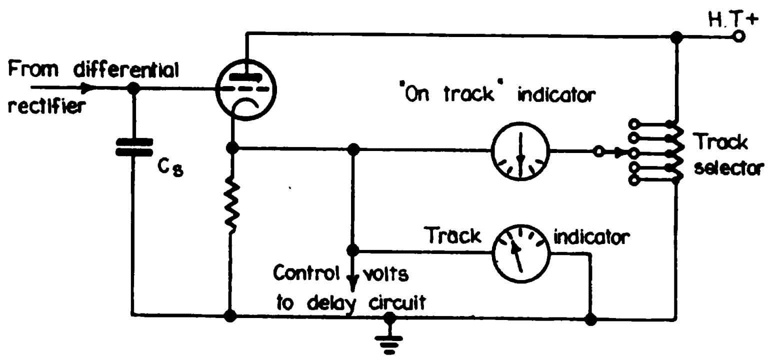

Figure 317.—Indicating system to facilitate navigation on any selected track of a multiple track system.

With both of these methods it is possible for the delay circuit to be triggered by a fortuitous arrangement of interference pulses but, provided the rate of triggering from this source does not exceed a few per cent of the rate of triggering by the desired pulses, no harm will be done since the delayed gates which are normally locked to the slave pulses will on these occasions " see " very few pulses—again by chance coincidence with interference pulses. The net effect of these pulses on the tracking will cancel out since there will on the average be as many coincidences with one gate as with the other.

The indicator in this system may be marked in terms of time delay or suitably numbered tracks and to facilitate navi-

gation on any desired track a track-selecting switch may be provided together with a centre-zero instrument for indicating deviation to port or starboard of the selected track. This is very simply accomplished by a bridge network as shown in Fig. 317.

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